STORAGE TUBES FOR USE AS MEMORY UNITS IN ELECTRONIC DIGITAL COMPUTERS

BY

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PREFACE

This paper has been written as a result of the author's interest and study of electrostatic storage tubes and their uses for the past four years. Although the literature is quite extensive on the subject of storage tubes, specific articles generally deal with individual tubes and their operation. It is felt that this does not fill the need of the casual reader who is interested in a general understanding of the principles of electrostatic storage. It is the aim of this paper to fill that need.

Although specific tubes are discussed, anyone interested in the basic principles of secondary emission, which is the basis of all electrostatic storage devices, can read part II of this paper and obtain a general understanding of storage tube operation without reference to the remaining parts of the paper. With this as a foundation, the author hopes that the reader will be able to better understand the operation of any tube he desires to investigate.

As a part of the curriculum in Engineering Electronics at the United States Naval Postgraduate School the author spent eleven weeks at the R. C. A. Tube Plant, Lancaster, Pennsylvania, working as a Junior Engineer on storage tubes. The author is indebted to the members of the Pick-up and Photo-tube group, with which he worked, for the many interesting and informative discussions held on storage tubes. He also wishes to express his appreciation for the many helpful criticisms given by members of the group during

the writing of this paper.

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TABLE OF SYMBOLS AND ABBREVIATIONS

I_1	Primary beam current
I_2	Secondary beam current
I_r	Current due to secondary effects
	Secondary emission ratio
V_k	Cathode potential
V_c	Collector potential
V_g	Target potential

CHAPTER I

INTRODUCTION

Recent developments in electronic circuits have made it possible to perform the elementary functions of arithmetic with great speed and accuracy. As a result problems in mathematics and science whch have long been considered unsolvable because of the enormous amounts of time and labor involved, are now being solved with the aid of these circuits.

The electronic calculators which utilize these circuits are the natural outgrowth of the efforts of man to find aids to the solution of every day problems requiring the use of mathematics. Perhaps the earliest record of a computer is a dissertation on the use of the abacus by Egyptians and Greeks written by Herodotus in 450 B.C. From this elementary machine we have progressed to the large scale digital computers now in use, which are capable of solving the complex problems posed by modern science.

The present era in computing devices can be considered to date from 1938. This era is marked by two developments of great importance. One is the stress on large scale computing equipment, primarily digital devices, the other is the development of electronic techniques capable of satisfying the needs of these devices. As the capacity of computers increased so did the physical size and the need for smaller more reliable components was brought sharply into focus.

From these requirements came the development of the electrostatic storage tube for use as the memory element in digital computers. The principles of operation of "memory" or "storage" tubes have been known for many years but only in the last few years has practical usage been made of these principles.

Basically, the operation of a storage tube is dependent on the emission of secondary electrons from a surface, either a metal or an insulator, when the surface is bombarded by a stream of primary electrons. Much of the early work in determining the effects of electron bombardment on various materials was done in Germany by Daene, Schmerevitz, Knoll and others. Most of the work done in this country dates from 1940, resulting in part from the increasing interest in television. However, the work done in the field has brought forth many uses for storage tubes. Television, moving-target indicators, and storage of radar signals are only a few of the systems utilizing these tubes. Unfortunately the scope of this paper does not allow a complets coverage of all storage tubes. Any reader interested in further study of the field is referred to the bibliography.

The possibility of using storage tubes in digital computers was not seriously investigated until the end of the war. In the period from 1946 up to the present, many laboratories have developed storage tubes, having many different modes of operation, but all based on the principles of secondary emission.

It is the purpose of this paper to present a discussion of storage tubes as used in computers. Emphasis is placed on tube operation alone with no reference to the external circuits involved. Only a small portion of the paper will deal with digital computers, and the discussion in this section will be very general.

One section pertains to the principles of secondary emission. In order to understand the operation of storage tubes the reader must understand the phenomenon of secondary emission. An attempt has been made to write this section as clearly and consisely as possible. It is hoped that anyone with some knowledge of electronics will be able to fully understand the behavior of a surface when under electron bombardment. This section assumes that the reader has no previous knowledge of secondary emission, and is written accordingly.

Part four of the paper is devoted to a discussion of three different computer storage tubes; the RCA SB-256, the MIT Whirlwind computer tube, and the Williams tube. There are other storage tubes which have been developed for use in computers. The three chosen use three different approaches to a common problem. If the operation of these three is understood, the reader will have a good knowledge of storage tube techniques as applied to digital computers.

CHAPTER II

DIGITAL COMPUTERS

A digital computer is one which performs mathematical operations with numbers expressed in the form of digits which can assume only discrete values. Assuming that all operations are performed accurately, the precision of the computation is dependent upon the number of digits the machine can handle.

That portion of a computer which actually performs the mathematical functions in the solution of a problem may be termed the operations system. It consists of arithmetic units, which perform the operations of addition, subtraction, multiplication, and division; storage units, which provide means for holding information for reuse; and control elements, which interpret commands and initiate arithmetic processes.

From the engineering standpoint, the problem of electronic digital computing lies primarily in the construction of suitable electronic devices having the same number of states as the number of possible values of a digit. In this way a one-to-one correspondence may be established between each state of the device and each value of the digit. Since, relatively, the complexity of the electronic device is dependent upon the number of values a digit may assume, it is naturally advantageous to use a system which can be represented electrically with ease and economy. For this reason the binary system has attained a great importance in the computer field. Today, most digital

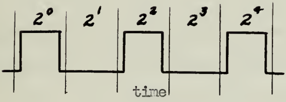
computers use the binary system, although some work has been done using the decimal system.

In the binary system only two modes of operation are required, namely, "on" or "off". Therefore, any two-state electronic device may be used to represent a binary digit. Examples of electronic digit representation which are useable are the numerous flip-flop circuits, difference in the level of two voltages, the presence or absence of a pulse, or electrostatic storage.

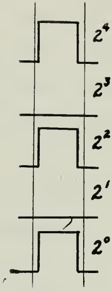
The first step in setting up a problem is to divide the problem into a sequence of simple arithmetic or logical operations externally, and construct a table of instructions for the machine. Each instruction will require that an elementary operation be performed on, or by, a number. This is referred to as moving a number from one "address" to another. To every address a digit combination will be assigned, so that an instruction consists of two digit combinations, and appears as a number. From this it is seen that instructions and numbers are similar. They are referred to as "words".

There are two different ways of handling numbers in terms of their binary representation. One is called the series method, the other the parallel method. In series operation, a number is transmitted from one place to another in the machine, a single digit at a time, until the entire number has been completed. In parallel operation, each digit of a number is transmitted on its own separate line, and all digits of a number are sent simultaneously.

As an example, the binary representation for the number twenty-one is shown for both series and parallel operation.



SERIES



PARALLEL

As usual, each system has advantages and disadvantages. The parallel machine is faster, but requires more equipment since each digit requires an individual line. In a series machine timing is important since successive digits of a number are distinguished from each other by their time of occurence. In a parallel machine the timing is unimportant since the digits of a number are distinguished by the place of their occurrence.

Since all the operations required of a computer cannot be introduced into the machine simultaneously, they must be remembered during the loading period and during operation, until each is used. The storage system provides this necessary "memory" for the machine.

It has been estimated (Sheppard,16) that a large scale automatically sequenced computing machine should have a minimum high-speed memory capacity of 1,000 words, where a word is made up of approximately 40 pulses. For large problems such as partial differential equations or problems in statistics, a total memory of 10,000 to 1,000,000 words are required. From this it is seen that the minimum requirements for the type of operation desired are for the storage of 4×10^5 binary digits.

If a two tube flip-flop circuit were used then 8×10^5 tubes would be required; clearly an impractical situation from the standpoint of size, economy, and reliability. For this reason the electrostatic storage tube, which greatly reduces the number of tubes required by the memory unit, has assumed an increasing importance in the computer field in the last few years. By reducing the number of tubes, and providing reliable operation, the construction of large scale digital computers has become practical. For example the Williams tube (Williams,17) with a spot diameter of 1 mm, is reported to have a storage capacity of 1600 digits on a 6" cathode ray tube. The RCA SB256 (Rajchman 13) has a storage capacity of 256 digits in a tube 2" in diameter and 7" in length. Other tubes have been developed with sizes comparable to those mentioned, and all of them have the advantage of large storage capabilities in a relatively small volume.

In order to make use of the memory device it must be possible to insert, extract, hold or erase information as

desired by the operator. The process of inserting information into the memory unit is called "writing". When information is extracted or moved to another address it is "read". This does not necessarily imply permanent removal of the information from storage since it may be desirable to retain it for future use. To erase the information is to completely remove it from storage. In some cases this is done simultaneously with the writing of new information, thus eliminating one step in the process of reading and erasing prior to inserting new information.

From the proceeding discussion the requirement for a storage tube to be used as a memory unit for digital computers may be summarized as follows:

1. The tube must be capable of storing a large number of digits. This is necessary if a reduction in size of the equipment is to be realized.
2. Selection of address must be done with absolute certainty. Reading or writing into an address in error could result in nullifying large amounts of work.
3. Written information must be stored indefinitely. Changes in stored signals can result only from writing or erasing processes.
4. Access time must be short; i.e. the time required to write information into or read from a given address must be short compared to the time required for an overall operation.

The remainder of this paper describes the manner in

which electrostatic storage tubes operate and how they meet the requirements as stated.

CHAPTER III

PRINCIPLES OF SECONDARY EMISSION

The basic principle underlying the operation of all electrostatic storage devices is the emission of secondary electrons. These secondary electrons result from the bombardment of a surface by a stream of primary electrons. As was pointed out in the previous section, the memory section of a binary computer needs only to retain "yes" or "no" information. Consequently, if a surface is bombarded with a stream of electrons in such a manner as to leave either a deficiency or an excess of electrons at a given spot, then each spot that is bombarded can represent either a "yes" or a "no." Assuming the charge pattern is retained by the surface after the bombardment, then this surface can serve as a memory device. If the storage surface contains thousands of these spots, each one insulated from the others, and each one capable of assuming either a positive or negative charge, then the surface is capable of storing large amounts of digital information. Actually there are many substances or composites of substances that have this property of assuming a positive or negative charge under the influence of electron bombardment.

For example, mica, if bombarded point by point by a stream of electrons of varying intensity, will become a surface made up of many "islands" of charges. Since mica does not conduct transversly, and if leakage is neglected, then each of these islands will be insulated from the others,

and their charges will be retained by the mica. The magnitude of these charges will be indicative of the intensity of the electron stream at the time of bombardment. If, at a later time, the mica surface is in some fashion interrogated point by point, then a reproduction of the original charge pattern is obtained. In this way information has been written, stored, and read; thus the primary requirements of a storage unit have been met.

Insulating surfaces such as mica are not the only ones exhibiting the properties of secondary emission and charge storage. Surfaces have been formed by evaporating metal on an insulating plate in such a manner as to form many small islands of metal which will be insulated each from the other. With this type of surface the same procedure of depositing and removing charge can be followed as given for mica and the storage principle results. There are many other ways of making and using storage surfaces but they are of no specific importance for this discussion. Where actual tubes are described, the target composition will be explained.

The foregoing has been brief and oversimplified. It is intended only to show the reader why electrostatic storage, using the principles of secondary emission, is being used as a memory device. With this as a background it is hoped that the reader will have a better appreciation of the material which follows.

1. Secondary Emission Characteristics.

Fig.1 shows the general shape of the secondary emission characteristic of a storage surface. It is a plot of the gain or loss of electrons on a storage target versus the target potential, when the target is bombarded by a stream of electrons. The target potential is taken with respect to the electron source. The gain or loss of electrons is plotted as a ratio of the number of secondary electrons leaving the target to the number of the primary electrons impinging on the target. This is defined as the secondary emission ratio of the target surface and represents the number of secondary electrons emitted per primary electron reaching the target. This is, of course, a statistical average since the number of secondaries emitted per primary will vary widely.

As Fig.1 shows, the secondary emission ratio varies with different values of target potential. This is due to the capture of primary electrons by the storage surface, and to the emission of secondary electrons by the surface. In order to understand these actions as they take place a basic tube will be hypothesized. Consider a tube shaped similar to the conventional cathode-ray tube. At one end is inserted an electron gun which supplies the primary bombarding electrons. At the other end is a sheet of dielectric, e.g. mica, which will be the storage surface. Near the target is inserted a collector anode which will operate at a potential always higher than that of the target. This will serve to collect any electrons drifting

in the tube because of reflections and will collect all secondary electrons emitted from the target surface.

The cathode will be held at ground potential and the beam accelerating potential, or target potential, will assume various positive values. The results will be plotted (Fig.2) as the <u>effective</u> secondary emission ratio versus target potential. In this case the number of electrons collected by the target includes both the number due to secondary emission and the number due to electron optical effects and reflections from the target. If I_1, represents the primary or beam-current, I_2 represents the secondary emission current and I_r represents those electrons collected because of the secondary effects noted, then the <u>effective</u> secondary emission ratio is represented by $(I_2 + I_r)/I_1$. This is not to be confused with the plot of Fig.1 which is the plot of I_2/I_1 and is the true secondary emission ratio.

When the accelerating potential is slightly positive with respect to the cathode the primary electrons arrive with insufficient energy to free an appreciable number of secondary electrons, and the arriving primaries are held by the target because of the field between the target and the cathode. This results in a secondary emission ratio less than unity. As the accelerating potential is gradually increased more primaries reach the target but the number of secondaries emitted is still small. This gives a net decrease in the secondary emission ratio. This effect continues until a minimum point in the curve is reached.

For accelerating potentials past this point the ratio starts to increase and continues to do so until a point is reached where the number of secondary electrons emitted by the target just equals the number of primary electrons that strike the target. This is referred to as the first crossover point. As the accelerating potential is increased beyond this point the secondary emission ratio becomes greater than unity, that is, there are many more electrons leaving the target than there are primary electrons striking it. The ratio increases with increasing potential until a maximum is reached. As the potential is increased further, the energy required for electrons to escape from the target also increases, and the secondary emission ratio begins to fall off until it passes through unity and again becomes less than one. This second point of unity secondary emission ratio is known as the second crossover point or the "sticking" potential of the target.

Both Fig.1 and Fig.2 are general curves; that is, the secondary emission from all emitting surfaces will be of the shapes shown although actual values may differ. For example, the maximum secondary emission ratios for insulators may vary from 1.5 to 7.5 while for metals the secondary emission ratios vary from 0.6 to 1.6 (McKay 11). These figures are intended to give an idea of the range of variations for different substances and are not intended as maximum values for insulators and metals.

Using the same tube as previously described, suppose

the collector anode is operated at a potential that is between the first and second crossover points of the target. Using the same procedure as given previously, the accelerating potential is again gradually increased and the effective secondary emission ratio is plotted against the beam acceleration voltage. The result is shown in Fig. 3. It is seen that for accelerating potentials considerably less than the collector potential, there is little or no deviation from the curve of Fig.2. In this low-potential portion of the curve, the collector serves only to catch the secondary electrons emitted by the target and since the potential difference between collector and target is relatively large the emission characteristic is not changed. However, for accelerating potentials in the neighborhood of the collector potential the curve is radically changed. Here the curve shows that the second crossover point is determined by the collector potential and <u>not</u> by the Characteristic of the emitting surface. Also note that the target potential at the second crossover is a few volts positive with respect to the collector.

This is due to the following action. Once the secondary electrons are emitted by the surface they are either collected by another electrode or they may partly or completely fall back on the emitting surface. Their action will be determined by the electric field in the vicinity of the emitting surface and the energy with which they are emitted from the target surface. Fig.4 shows the general relation between the energy of secondary electrons emitted

from a target surface and the number of secondaries emitted per unit energy level. Once again it is to be noted that this is a general curve. Actual values may vary for different materials. Reference to the curve shows that the large majority of secondary electrons are emitted with energies of a few volts. These are regarded as true secondaries. Merged with this group and extending out somewhat uniformly to energies almost equal to the accelerating potential, is a small number of inelastically reflected primaries. At a velocity corresponding to the accelerating potential there is a peak of elastically reflected primaries. Actually only the low velocity "true secondaries" will be considered since the reflected primaries are relatively unimportant. Now, if N electrons in the primary beam strike the target, the area under the curve of Fig.4 will be σN, the total number of secondaries emitted, where σ is the secondary emission ratio. Due to the space charge existing between the target and collector* equilibrium will occur for the target at a potential of V_e with respect to the collector. At this potential the number of secondaries with sufficient energy to reach the collector is just equal to the number of primaries striking the target i.e., the secondary emission ratio is equal to one. These secondaries are represented in Fig.4 by the area under the curve from V_e to infinity. The remaining secondaries $(\sigma - 1)N$, represented by the area from 0 to V_e will have insufficient energy to penetrate the space charge and will fall back on the target

* This is analagous to space charge effects in a diode.

From this it is seen that the target will have a potential slightly positive with respect to the collector at the second crossover. In general, this potential difference is only a few volts. Some variation will be noted for different target materials and will be dependent on the energy distribution of the secondaries from each material.

Referring again to Fig.3 there are three points of operation that are very important; the cathode and second crossover, which are points of stable operation; and the first crossover or point of critical potential, which is a point of unstable operation.

Consider the case in which the beam is turned on and the accelerating potential is held just under the critical potential. Since the secondary emission ratio is less than unity in this region all primary electrons arriving at the target will be held and a negative charge will accumulate. This action continues until the point under bombardment accumulates enough negative charge to reach cathode potential. Once cathode potential is reached, the beam will not reach the target and the surface will rest at cathode potential. If charge leaks off the target surface and it tends to go slightly positive, enough electrons will strike the target to return it to the cathode potential.

With the tube again in its quiescent state, the gun is directed at another spot, the beam turned on, and the beam accelerating potential held just above the critical potential. In this region the secondary emission ratio is greater than unity so the arriving primaries will release

secondaries in a larger number than the arriving primaries. Because of this net loss of electrons, the target surface will charge positively and continue to do so until the target reaches collector potential. If the accelerating potential should be greater than collector potential, then Fig.3 shows the secondary emission ratio will be less than unity and the target will charge back down to collector potential. Thus it is seen, that regardless of the accelerating potential, one of two potentials will be reached, either that of the cathode or that of the collector.

The preceeding material has been presented in an attempt to explain the characteristics of secondary emission. It now remains to be seen just how these characteristics can be put to practical use in the storage of binary digital information. It was pointed out in an earlier section that three conditions must be met in order to have a satisfactory memory unit for a digital computer; the unit must be capable of having "yes" or "no" information written on at any time, it must be able to store the information for long periods, and the information must be readily available for reading. Several ways of performing these functions will be presented. The reader should remember that these methods of writing, retaining and reading are merely representative. It is intended that this section merely presents basic ideas so that the operation of the tubes described in later sections will be better understood.

2. Writing.

For purposes of explanation, the same tube will be used as previously hypothesized but with one change. The dielectric target will be mounted on a metal plate which has an external connection. Now by varying the potential of the metal plate, the surface of the dielectric will also change by the same potential due to the capacity action of the dielectric. For example, if the target plate is suddenly pulsed negative 50 volts with respect to the cathode, then capacity coupling will cause the dielectric surface to also drop by 50 volts with respect to the cathode. Conversly, a positive pulse applied to the target plate will cause the dielectric surface to go positive by a like amount.

There are now three elements in the tube whose potentials are readily variable. They are the cathode, the collector, and the target. In the writing methods to follow, two of these elements will have their potentials held constant while the third is varied. Since only "yes" and "no" information is required, in two of the methods to be described the two stable potentials which the target will assume will be cathode and collector potentials, representing the digits 0 and 1. In a third method the target will assume two different values of collector potential which will represent the digits 0 and 1.

For the first example of writing, assume the collector and target potentials are not changed by external means, but the cathode potential is varied. In its quiescent condition the target will be connected to ground through a

high resistance. The collector will be at some potential above ground. The first crossover will occur at some point just negative to ground and the cathode will be very negative with respect to ground. This is illustrated in Fig. 5. V_k is the cathode potential; V_g the target potential; and V_c the collector potential. The electron beam will be controlled by the electron gun.

Assume that with the potentials as shown in Fig.5 the electron beam is turned on and directed at one spot on the surface of the dielectric. Since the target potential lies between the first and second crossover points, the secondary emission ratio from the surface of the dielectric will be greater than unity. Consequently the spot being bombarded will assume positive charge and move to collector potential where it will stay.

The electron gun is now directed at another spot on the target surface. However, the cathode potential is moved toward ground, i.e., made less negative, before the beam is turned on. This has the effect of shifting the curve to the right by an amount equal to the change in cathode voltage. Since the target is at ground potential it will remain stationary. Assume the shift is large enough for V_g to fall to the left of the first crossover point. Under this condition the secondary emission ratio will be less than unity, and the target spot will gain electrons and charge down to the cathode potential.

Thus by varying the cathode potential and bombarding

the target, two separate spots have been charged to different potentials; one to cathode potential and one to collector potential. These two spots can represent the digit 0 and the digit 1.

Another method which can be used in writing is to vary the collector potential while maintaining the cathode and target plate at a constant potential. In this case the collector potential is varied between two values and the target is charged to that potential. With this scheme the two stable potentials which the target will assume under bombardment are both collector potentials; no target spots are charged down to cathode potential.

For example, consider Fig.5 used in the preceding case. With the potentials as shown the gun is directed at a spot and the electron beam turned on. Because the secondary emission ratio is greater than unity, the spot will charge to the collector potential. Now with the gun directed at another spot, the collector potential will be changed by some given amount and the beam again turned on. The spot being bombarded will charge to this new collector potential. Thus there are two spots on the dielectric surface, both positive by different amounts with respect to the cathode, and both at stable operating points. In this case the digit zero can be represented by the lower potential since neither spot will be at cathode potential. It is to be remembered that a dielectric is being bombarded and once bombardment

ceases the charge deposited remains fixed even though the collector potential is changed.*

The last writing method to be described is possibly the most widely used. It consists of varying the potential of the metal backing plate upon which the dielectric target is mounted while holding the cathode and collector potentials constant. Here the dielectric potential will be varied by the capacitor action which results when the target plate potential is varied. As in case one the two stable points will be cathode potential and collector potentia; representing the digits 0 and 1.

As was explained in an earlier section, once a stable operating potential is obtained, a given spot will maintain this potential while the spot is being bombarded and for a considerable period after bombardment has ceased. For example, if a spot is at cathode potential and the beam is on, no electrons will reach the spot since there is no field between the spot and the emitter, both being at cathode potential. If the beam is turned off the spot remains at the cathode potential. Now, however, with the electron gun still directed at the same spot, suppose the target plate is pulsed with positive potential greater than the first crossover potential of the dielectric material. By capacity action of the dielectric, the target surface will also go positive by this amount. Consequently the electron gun is now bombarding a spot whose potential is great

*This statement neglects secondary effects. See page 25

enough to make it lie in a region where the secondary emission ratio is greater than unity. As a result the spot rapidly charges to collector potential and assumes a new stable operating potential. In other words, the spot has been changed from a digit 0 to a digit 1. If the spot had originally been at collector potential and the same positive pulse applied, the target would have gone more positive by the amount of the pulse, but as Fig.5 shows, this would have placed the target in a region where the secondary emission ratio is less than unity. As a result the spot would be charged down to collector potential. Thus it is seen that regardless of the original potential of the spot when a positive pulse is applied the result is a spot at collector potential. In this way the digit 1 is always stored when a positive pulse of sufficient magnitude is applied to the target plate. A pulse applied for this purpose is called a writing pulse.

In a similar manner any spot may be forced to assume cathode potential by the application of a negative pulse. In this case the negative pulse must be large enough to drive any spot on the target surface that is at collector potential below the first crossover point or critical potential.

Although the positive or negative writing pulse is applied to the target plate and consequently to the whole surface of the dielectric, no change will take place at the spots not under bombardment. This results from the fact that, although their potential may go above or below the

critical potential, there will be no change in charge since no electrons will be striking these points.

At this point a logical question arises. What happens to the spot under bombardment when the pulse is removed? For example, a spot is at cathode potential, a positive writing pulse is applied to the target plate driving the target above the critical potential; as a result the spot under bombardment charges to collector potential. Now the pulse is removed, forcing the target plate potential back down past the critical potential. What prevents the spot from again assuming cathode potential? The answer lies in the manner in shich the writing pulse is removed. If the applied pulse was a square wave then the target spot would always return to its original condition. However, if the trailing edge, instead of having a steep slope is made to drop off slowly, then the target spot under bombardment will recover more rapidly than the pulse decays. For example refer to Fig.3. Assume the target has been pulsed positively and the spot under bombardment is at collector potential. Now instead of dropping the pulse sharply, which would drive the target below the critical potential, let the pulse drop off in staircase fashion i.e. in short drops with respect to time. See Fig.6. Now as Fig.3 shows, each time the target potential drops a small amount it will charge back to collector potential since the secondary emission ratio is always greater than unity. Thus by dropping the target plate potential in

this fashion, the pulse can be removed without disturbing the charges deposited on the target surfaces. In practice the trailing edge of the pulse is actually a sloping line and not a series of drops.

In this discussion of writing principles, idealizations have been made which are not entirely valid. The principal one is the assumption that each spot of the dielectric can be charged independently of its neighboring spots. With two spots on the dielectric surface charged to different potentials an infinite resistance cannot exist between them and leakage will occur. There is also the effect of small fields generated by the charged spots which cause some reaction between the charged regions. These and other secondary effects are of extreme importance and must be considered in producing an operable tube. However, they are too basic and their causes too extensive to be considered in this paper. Some of these secondary effects enter directly into the operation of the Williams Tube and will be covered in the description of that tube.

3. Reading:

Several methods are used in reading the signal stored in a memory tube. In general, they depend on the presence or absence of secondary electrons when the target is bombarded with primary electrons, or else on the difference in the number of secondary electrons emitted when the target is under bombardment. The only methods to be described here will be those which can be easily used with

the writing techniques described. Any system used will be dependent on the manner in which the stable operating points are utilized and on the construction of the tube. In some cases separate electron guns are used for the three functions of writing, reading and holding. The trend, however, is toward one gun capable of performing these three functions. This naturally leads to a smaller, more compact tube, a feature which is highly desirable for any tube to be used in computers.

In the first system of writing described in the preceding section the cathode potential was varied in order to produce the two equilibrium points, cathode potential and collector potential, which represent the digits 0 and 1. Reading can also be accomplished by varying the cathode potential, but in this case it will be varied to a value different from that used in writing. Let the cathode potential be dropped to a value such that the original cathode potential now becomes the point of minimum secondary emission ratio on the curve. (Fig.3) At this point on the curve the secondary emission ratio is practically zero. The collector potential remains fixed. Now the digit 0 is represented by a point of almost zero secondary emission ratio while the digit 1 is still represented by the collector point on the curve, with a secondary emission ratio of unity. When the electron beam scans the target area, the secondaries emitted from a spot originally charged to cathode potential will be practically non-existent, while those

emitted from a spot charged to collector potential will just equal the number of primaries impinging on that spot. These secondaries are collected by the collector, thereby providing an output of two different levels; one representing the digit zero and one representing the digit 1.

This method of reading permits the reading of a stored signal without removing the signal from the target surface. At collector potential there will be no net gain or loss of charge, consequently the target potential remains fixed; at the point of minimum secondary emission some gain of negative charge will result, tending to drive the spot below the original cathode potential. However, when the cathode returns to its original condition, this excess charge will leak off leaving the spot at cathode potential.

In the second method of writing, only the higher stable potential was used. Here the two digits were distinguished by having the collector assume a different value for each spot while the charges were being deposited. Let these two points be V_1 for the digit 0 and V_2 for the digit 1. Now in reading, the collector potential will be set to a value that is mid-way between V_1 and V_2 which can be called V_0. This results in a new equilibrum point V_0, toward which V_1 and V_2 will charge when bombarded by a stream of electrons. V_1 will be below this point and V_2 will be above it. From Fig.7 it is seen that V_1 will have a secondary emission ratio greater than unity as it charges toward V_0, and V_2 will have a secondary emission ratio less

than unity as it charges toward V_o. Consequently as the target is scanned, the collector output from the spot corresponding to V_1, will be large, while the collector output from the spot corresponding to V_2 will be very small. In this manner the two digits are identified.

It should be noted that this method of reading destroys the information stored on the target surface. Since both spots charge toward a common collector potential when the reading takes place they both assume the same charge and are indistinguishable. This is naturally undesirable where it is necessary to refer several times to a given address for the information stored there, since rewriting would be required after each reading.

In the last writing method described the collector and cathode potentials were constant and the target plate potential was varied. The two stable potentials to which the spot under bombardment charges were used; cathode and collector to represent the digits 0 and 1 respectively. In reading, essentially the same procedure is used as in writing in that only the target plate potential is varied. Consider that the target surface has information written on its surface, the information consists of the digits 0 and 1. To read off the information the electron gun is set to scan either the complete target area or only certain addresses, whichever is desired. At the instant the electron beam is turned on, a small negative pulse is applied to the target plate. Due to capacity action the

target surface will also go negative by an amount equal to the magnitude of the pulse. When the beam strikes a spot that was originally charged to collector potential it will be less than collector potential by an amount equal to the negative pulse. Consequently the secondary emission ratio will be greater than unity and secondaries will move to the collector, producing an output signal. When the beam is directed at a spot originally at cathode potential no secondaries will be emitted, and no signal output occurs. This follows since the effective secondary emission ratio is unity at cathode potential and for potentials slightly less than that of the cathode.

Since the original conditions of equilibrum, i.e. spots at cathode or collector potentials, remain after the pulse is removed, this method of reading permits successive reading without destruction of the spot charges.

4. Holding:

It has been stated previously that for the sake of clarity secondary effects were being omitted in this discussion and would be assumed to be negligible. If this assumption were entirely valid then there would be no mechanism required to hold the charges on the target once they were written on. Unfortunately, leakage of charge from the dielectric cannot be ignored since it is present and will cause a change in potential of the various spots if it is not prevented or corrected. For this reason some form of "holding" is employed. In some cases the whole

target surface is sprayed with a shower of electrons. In this case if charge is lost by the spots at cathode potential because of leakage then enough electrons will be allowed to reach the spot to replace those lost, thus maintaining the spot at equilibrum. For those spots at collector potential, any charge lost will drop the spot potential below collector potential into the region where the secondary emission ratio is greater than unity. Thus the spot will charge back up to collector potential under the steady bombardment of the holding gun electrons. Effectively the spot will never go below collector potential since the action described is quite rapid.

Another method of holding is to employ a system of reading that does not destroy the charge pattern. Since a system of this type tends to restore any charge that has leaked off, if reading is done at systematic intervals the charge will be restored each time a spot is interrogated.

There are many systems employed for retaining the charge on a storage surface, and most of them are peculiar to the tube construction, the number of guns used, and the reading and writing system employed. Therefore, rather than give a detailed description of several methods employed in different tubes, the holding system in those tubes discussed in this paper will be explained since they are considered representative.

This concludes the section of Secondary Emission. The next part of this paper will deal with three electrostatic storage tubes; (1) The RCA SB-256, (2) The MIT

Whirlwind Tube, and (3) The Williams Tube. These tubes were designed for the specific purpose of providing the memory unit in digital computers. Although other storage tubes have been suggested as being suitable for use in digital computers these three are being presented since each tube is entirely different from the others. Operation of each of these three tubes is based on the principles of secondary emission, but in each tube these principles are utilized in a different manner to produce similar results.

CHAPTER IV

STORAGE TUBES

R.C.A. SB-256: (Rajchman, 13,14) This tube was developed by R.C.A. for the specific purpose of use in a digital computer. The work was done by the laboratories at Princeton in collaboration with the Institute of Advanced Studies as a part of their work to develop a universal electronic computer. The tube was designed primarily as an attempt to meet, as nearly as possible, the ideal requirements of the inner memory of a computer, as were set forth in an earlier section of this paper. Emphasis is placed on reliability of operation and short access time.

The principle of the tube depends on quantizing both the address of the stored information and the information itself. The selection of the address is obtained by means of two orthogonal sets of parallel spaced bars which form a series of windows. Eight elongated cathodes are used to produce a steady shower of electrons which rain continually on these windows. Address selection voltages are applied to certain groups of bars connected in pre-determined combinations. Depending on the voltages applied, some windows will assume a potential condition that will allow the passage of electrons, others will prevent the passage of electrons. Located behind the windows are small metallic islands, each insulated from the others. The storage of information is made in terms of one of the two stable potentials which can be assumed by an island when under

bombardment by a stream of electrons. Reading signals are taken off electronically or may be observed visually.

1. Description of Tube.

The SB256 is a cylindrical tube 3" in diameter and 7" long. All connections are made at one end of the tube, which utilizes a 34 lead stem. There are 256 storage elements. The eight elongated cathodes have a rectangular cross-section and are located in a diametral plane of the tube. Between and parallel to the cathodes are a set of nine selecting bars of square cross-section. Thes vertical selecting bars are connected into 6 groups: V1, V2, V3, V4 and V'1, V'2 as shown in Fig.8. On either side of the plane of the cathodes and V-bars there is a set of 18 parallel bars of square cross-section which are placed at right angles to the set of vertical bars. Together, these vertical and horizontal bars determine the window selection. The two sets of horizontal selecting bars sandwich the cathodes and vertical bars. The tube is symmetrical with respect to the cathode plane, consequently all subsequent electrods will also sandwich the cathode bars. This is shown in Fig.9. The 36 horizontal selecting bars are connected into 12 groups: H1 to H4 and H1' to H8' as shown in Fig.8. Actually the 9 vertical bars are used for 8 gates and the 36 horizontal bars are used for 32 gates, the excess bars being used to take care of end effects.

Moving outward on either side from the cathode plane, there is located, next to the horizontal selecting bars,

a collector. The collector is a flat metallic plate, perforated with round holes whose centers match the centers of the windows formed by the vertical and horizontal selecting bars. Adjacent to each collector plate there are two perforated mica sheets holding between them 128 metallic eyelets which are the storage elements. These storage eyelets are made of nickel plated steel and have a secondary emission characteristic similar to the one shown in Fig.9.

Another perforated metal plate follows the two mica plates. This is the writing plate. A similar perforated metal plate is located next to the writing plate. This is the reading plate. Each perforation in these plates and in the storage eyelets is in register with a window formed by two vertical selecting bars and two horizontal selecting bars.

Beyond the reading plate is a Faraday cage formed by two perforated plates spaced some distance apart and closed on all four sides by a metallic wall. A glass plate coated with a fluorescent material is placed against the outer plate of the cage. In the central plane of the cage there are nine wires spaced so as to be between the holes of the perforated plates. (See Fig.9). The wires are connected together and collect the secondary electrons emitted by the fluorescent material when under bombardment. This provides an electronic output for the tube.

2. Operation.

In describing the operation of the SB256 frequent reference will be made to Fig.9. This figure shows three possible conditions for any one eyelet to assume: (1) Eyelet at 0 volts. (all voltages with respect to the cathode) (2) Eyelet at +200v; reading plate at +150v (3) Eyelet at + 200v; writing plate at -100v. The electron paths resulting from these conditions are shown and will be explained.

In the quiescent state, assuming the tube is storing information previously written in, all of the selecting bars are at cathode potential (0 volts) and all other electrodes are at the potentials shown in Fig.9. In this condition, electrons emitted from the cathodes are focused into 256 beams by the combined action of the vertical and horizontal selecting bars at zero potential and the collector potential at 180V. The collector potential will focus the beam through the centers of the collector holes to the eyelets. Since the eyelets are mounted in the mica plates which serve to insulate each one and since the eyelets have no external connection, they are floating electrically; and when bombarded by a stream of electrons will tend to assume a potential such that the net current to each will be zero. As was pointed out in the section dealing with secondary emission, there are two such naturally stable potentials; either cathode potential or collector potential. Consequently by the manipulation of other parameters

each eyelet will be made to assume either cathode or collector potential. Once this condition is reached it can be held indefinately without deterioration by the constant shower of electrons.

3. Window Selection.

To write into or read from a memory element the quiescent state of the horizontal and vertical selecting bars must be momentarily disturbed so that the electron beams to all eyelets are interrupted except the beam to the eyelet selected for reading or writing. This is done by applying a negative pulse to all the horizontal and vertical selecting bars except one in each of the four groups V, V', H and H'. The bars are connected in such a way that only one gate in each of the V and H directions will have its two limiting bars remain at cathode potential, while all others will have one or both limiting bars at the pulsed negative potential.

When a horizontal or vertical selecting bar is made sufficiently negative, it cuts off most of the current from the adjacent cathode and the small amount of current which does pass is deflected and does not reach the hole of the collector. If bars on either side of a cathode are negative then a potential barrier is formed through which no electrons pass. Thus it is seen that only a window with its four selecting bars at zero potential will be "open" and pass the electron beam, while all others will be closed. For example, referring to Fig.8, if all vertical connections

except 1' and 4 are made negative, it is seen that only two adjacent bars are negative. If all horizontal connections except 1 and 1' are made negative, only two adjacent horizontal bars will be negative. Thus only the window formed by vertical bars 1' and 4 and horizontal bar 1 and 1' will be open, and electrons will be passed by this window while all others will remain closed. This holds true for any combination set up.

4. Writing.

To write into a given storage element current is passed to that element only, while it is interrupted to all others. A voltage pulse of the type shown in Fig.6 is applied to the writing plate. This pulse will have a value approximately that of the collector potential. Due to the capacity coupling provided by the mica support sheets, and since the eyelets are electrically floating, the potential of the eyelet will become that of the writing pulse and will be approximately that of the collector or greater. This follows since the writing plate pulse is approximately equal in magnitude to the collector potential.

Now assume that, as a result of previous storage, the eyelet is either at cathode potential or collector potential. If it was initially at cathode potential, the writing plate pulse will cause its potential to jump to approximately collector potential, and following the action described in Chapter II of this paper, it will charge to collector potential during the plateau of the pulse. If the eyelet

was initially at collector potential, the writing pulse will cause its potential to become approximately twice that of the collector. This places the eyelet in a potential area where its secondary emission ratio is less than unity, consequently it charges down to collector potential. Thus it is seen that regardless of the previous potential condition of the eyelet, at the end of the plateau of the writing pulse, the eyelet potential will be that of the collector.

The manner in which the writing plate pulse is removed determines whether the eyelet will assume cathode potential, representing the digit 0, or whether it will remain at collector potential, representing the digit 1. If it is desired to return the eyelet to cathode potential, a negative pulse is applied to one of the four window selecting bars, shutting off the current to the eyelet. At the same time the writing pulse drops slowly as shown in Fig.6. Since there is no current to the eyelet, the capacity between the eyelet and the writing plate results in the eyelet slowly dropping to cathode potential. If it is desired to have the eyelet remain at collector potential, the window remains open and the electron stream continues to reach the eyelet during the time the writing pulse is decaying. As previously explained in Chapter II, where the decay is sufficiently slow in impimging electrons overcome the potential drop due to capacity coupling and the eyelet is held at collector potential. Actually the decay is of the order of microseconds.

After the end of the writing pulse, current is

reestablished to all the eyelets by the end of the selecting pulse. All eyelets except the selected one simply went for a "potential ride", following the potential variations of the writing plate, but no net change was made in their potentials since no D.C. currents can be transmitted by a condenser. Therefore, at the instant current is reestablished, all eyelets except the selected one will be at its original potential. In this manner all eyelets have information placed on them in any order the operator desires.

5. Reading.

After the writing function is completed, all "windows" are open, allowing current to reach all the eyelets. Since each eyelet has a hole in its center, under certain conditions electrons will go through these holes. Fig.9 shows what happens to the electrons reaching the eyelets under three different conditions imposed by other elements of the tube.

In each case the cathodes and the selecting bars will be at zero potential. For case one the eyelet has assumed cathode potential, corresponding to the digit zero. Electrons will approach the eyelet, but since it is at cathode potential they will be repelled and no electrons will go through the hole. In case two the eyelet is at collector potential, consequently electrons will go through the hole and travel as far as the reading plate. Under writing or quiescent conditions the reading plate is maintained at - 100 volts. Since this is negative with respect to the

cathode, no electrons will be allowed through the reading plate holes and they will return to the eyelet. In neither case have electrons reached either the fluorescent screen or the reading wires.

The third case illustrated in Fig.9 shows the electron path when reading takes place. In its quiescent state the reading plate is biased negatively and the reading current going through the positive eyelets (case 2), does not reach the reading circuits. To read, an eyelet is selected by applying negative pulses to all but four bars as was done for the writing function. After a slight delay a positive pulse is applied to the reading plate, making it approximately 30 volts positive with respect to the cathode. This allows current to pass through the reading plate hole. The current passes into the Faraday cage and strikes the fluorescent screen, producing a light signal and also causing secondary emission which is collected by the reading wires. These wires are all connected in parallel and their output constitutes the reading signal.

Thus it is seen that when a positive eyelet is interrogated two output signals are obtained; visual, which can be used for monitoring purposes, and electrical, which can be used to operate other circuits. When a negative eyelet is interrogated no electrons penetrate past the eyelet, since it is at cathode potential, and no output is obtained. Thus "yes" and "no" information has been written into and read out of the tube.

The reading plate draws no current since its holes are in register with those of the writing plate and the Faraday cage. The Faraday cage potential determines only the intensity of the monitoring light obtained in the fluorescent screen, and has no effect on the reading beam. Its minimum is determined by the secondary emission properties of willemite (about +300 volts) and its maximum by breakdown. The reading wires are 200 volts more positive than the cage so that all secondaries emitted by the willemite screen will be collected.

6. Holding.

One point to be noted is that a minimum period of quiescence (all selecting bars at 0 potential) is required follwoing reading or writing for each eyelet prior to proceeding to another eyelet. In this period, slight deviations from their stable potentials, (cathode or collector potential) which the eyelet might have suffered due to leakage or other extraneous causes during the selection time, will be compensated for by electron bombardment. This provides for holding the stored charges. The action is similar to that described on page 29 of Chapter II.

If the minimum storage time; i.e. time the eyelets keep their information without benefit of the holding current, to the selection time is 1000, then the quiescent period need be only one thousandths of the selection period. However, no objectionable loss of repetition rate occurs if the quiescent period following each writing or reading is equal to one-half the selection period.

Detailed information on the operating characteristics of the tube is contained in the reports listed as references.

M.I.T. STORAGE TUBE, PROJECT WHIRLWIND: (Forrester, 4; Dodd, Klemperer, Youtz, 1)

The M.I.T. electrostatic storage tube was developed by the Servomechanisms Laboratory of the Massachusetts Institute of Technology for the Office of Naval Research. It is to be used as a memory unit for a parallel type digital computer. The desired goal is for reliable storage of 1,024 binary digits. At the present time lower storage densities give the high reliability required in a digital computer.

The tube operates on the principle of having discrete spots on an insulator surface charged to two different potentials. Information is deposited in the form of positive or negative signals which can be read out at any desired time. Address is obtained by accurate positioning of the beam of electrons emitted by the cathode. The tube operates with target plate modulation to produce the type charge desired on the target surface. Storage is in terms of the two stable points of operation, collector potential and holding gun cathode potential. Reading signals are taken from the target plate.

1. Description of Tube.

Figure 10 is a drawing of the M.I.T. tube, Dimensions are approximate. The target assembly is located at the right end as shown and the connections are brought out through this end. The other end of the tube contains two electron guns. One of these is used to read and write, the other to provide holding. The writing-reading gun is an ordinary cathode-ray gun which is electrostatically focused

and deflected. The deflection plates position a 50 microampre beam to a desired spot in the surface. The holding gun, which is a triode, provides a uniform spray of low-velocity electrons over the entire target surface.

Fig.11 is a schematic of the tube. The collector is a 100 mesh/inch wire screen held 15 mils in front of the storage surface. The dielectric plate is 4 inches in diameter and made of 5 mil mica. The storage surface is a mosaic of small squares of beryllim evaporated on the mica. This forms a series of conducting islands, which are the secondary emitters, each well insulated from the others. This mosaic is of about 40 squares per linear inch and is formed by evaporating the beryllium through a wire mesh. The writing-reading beam covers several of these mosaic squares at one time so that a single binary digit is stored on a spot consisting of 10 to 20 squares. The signal plate is film of silver on the mica sheet, and makes contact with a metal backing plate used to support the target assembly. Signal output is taken from the signal plate. The collector screen is always connected to ground.

2. Operation.

Input, or writing signals are applied to the target plate as either the presence or absence of a positive pulse, while a short duration positive pulse is simultaneously applied to the grid of the write-read gun. This results in the depositing of a charge on that part of the target surface at which the gun is directed. The charge on the

selected spot will represent either the digit 0 or the digit 1, depending on the presence or absence of the target plate pulse. The "zeros" are stored at the level of the holding gun cathode while the "ones" are stored at the level of the collector potential.

Output signals, corresponding to either a zero or a one, are obtained across the output resistor R_0 shown in Fig.11. The signals result when the reading gun is directed at a spot containing stored charges, and the beam is pulsed on. Positive or negative output pulses are obtained, depending on whether the spot being interrogated represents a zero or a one.

The holding beam is used to replenish the charge stored on the individual elements of the target surface, which may be decreased by leakage from the elements or which may be partially removed by reading. Holding is accomplished by flooding the storage surface with a uniform beam of low-velocity electrons.

Selection: Deflection circuits, which are controlled by the external circuits of the computer, position the electron stream from the write-read gun of the tube.

3. Writing.

To write on the storage surface, deflection plate voltages are established to deflect the beam of the writing gun to the desired spot. The beam will cover from 10 to 25 of the mosiac squares. It will be assumed that previous writing exists over the face of the target since the holding

beam is always in operation. This means that each spot is charged to either collector potential, which is zero volts, or to the holding gun cathode potential which is - 100 volts.

To write positive, i.e. to charge a spot to collector potential, the writing beam is biased on, with the target plate connected to ground. Since the writing gun cathode is at - 2000 volts the spot under bombardment will have a secondary emission ratio greater than unity. This holds whether or not the spot is at zero or - 100 volts potential. Consequently, the spot under bombardment either stays at collector potential or charges to collector potential, depending on its original condition.

To write negative, i.e. charge a spot to - 100 volts potential, a positive gate of + 100 volts is applied to the target plate, and the writing gun beam pulsed on. This + 100 volt gate will be capacity coupled to the target surface, raising the potential of each spot by 100 volts. Now, with the writing gun beam on, if the spot was originally at collector potential the 100 volt pulse will force the spot above collector potential. This puts the spot in an area where the secondary emission ratio is less than unity and it will charge down to collector potential. If the spot selected was originally at -100 volts then the target plate pulse raises it to collector potential where it remains during the period of bombardment. Thus the selected spot is charged to collector (ground) potential regardless of its former state. The beam is then biased off, the signal plate

gate removed, and the spot which was bombarded is dropped to -100 volts by capacity action. All other spots will have gone for a "potential ride" and will be returned to their original state.

Thus, if the writing gun beam is pulsed on with the target plate at ground (no gate) the selected spot is charged to collector potential, representing the digit 1. If the target plate has a + 100 volt gate applied, the selected spot again assumes collector potential during bombardment, but drops to the holding gun cathode potential (-100 volts) when the gate is removed. The writing action is seen to be independent of the potential of the spot prior to writing; therefore no erasure is required for the storing of new information.

4. Reading.

After completion of the writing operation the target surface is an array of charged spots. The digit 1 is represented by those spots at ground potential; the digit 0 is represented by those spots at -100 volts potential.

Reading is done in such a way as to detect both positive and negative regions. In video reading, i.e., d.c. pulses applied to control grid, a positive output is produced by the digit 0, and a negative output is produced by the digit 1. In order to produce a reading signal the target plate is gated to some intermediate voltage, say 50 volts. This gating signal is transferred by capacity action to the previously charged spots. Thus the digit 1

changes from ground to +50 volts and the digit 0 changes from -100 volts to -50 volts.

The reading beam is pulsed on and directed to the desired address. A spot resting at +50 volts will have a secondary emission ratio less than unity and will charge down to collector potential. This produces a negative output pulse from the target plate across the output resistor R_0. For a spot at -50 volts the secondary emission ratio will be greater than unity and it will lose electrons until it reaches collector potential. This produces a positive pulse from the target plate across R.

In computer operation r - f reading is used rather than video reading as described above. Instead of applying a video pulse to the reading gun control grid, a 10 mc. r - f pulse is applied. This provides a means of separating the output signal from the 50 volt gating pulse that is applied to the target plate. The radio frequency signal is then amplified and detected in a phase sensitive circuit, giving video output pulses of both polarities.

In order that the information stored on each of the elements may be retained for several reading, the reading beam current must be small. In this way the actual shifting of the original potential toward that of the collector will be small when a spot is bombarded. Immediately after reading the holding beam is switched on and the charges lost during reading can be replenished.

To clarify the previous paragraph, remember that the gating voltage is a 50-volt pulse. When gated on, all spots

are raised by 50 volts. The reading beam tends to charge those at +50 volts down to collector potential and charge those at -50 volts up to collector potential. When the gating pulse goes off each spot will drop by 50 volts. If the actual change in charge due to the reading beam is small, those spots that were at collector potential prior to reading will be slightly below collector and those spots at -100 volts will be slightly more positive with respect to the collector. The holding beam then returns each spot to its original condition.

If a large signal output is desired, this system cannot be used and reqriting must occur after each reading.

5. Holding.

During the period between writing and reading it is necessary to compensate for the loss of electrons due to leakage of the stored charges from the various spots, or due to small signal reading as previously described. This is done by static holding, i.e. charge is replenished by a steady spray of electrons over the target surface. A separate holding gun is used, its cathode operating at -100 volts to hold the stored signals at their two stable points, -100 volts and ground.

Refer to Fig.3. The first crossover of beryllium is at approximately 50 volts above cathode potential. That gives the following arrangement: cathode at -100 volts, first crossover of target at -50 volts and the target mosiac charged to either -100 volts or to ground collector potential.

With the holding gun on, consider what happens to a spot charged to -100 volts. If the spot is actually at -100 volts or slightly below, then no electrons reach the spot since no potential difference exists between that spot and the electron gun. However, if leakage or reading causes a deficiency of electrons from a spot, then it will go slightly positive with respect to the cathode, and holding - gun electrons will strike the spot with a few volts energy. Since the secondary emission is less than unity the spot gains electrons and charges down to the cathode potential. In this manner any spot charged to -100 volts is held at that potential until reading takes place.

If a spot was originally charged to ground potential then this will correspond to the second crossover shown in Fig.3 since the collector is at ground potential. Since this spot is at ground potential holding-gun electons will strike the surface with 100 volts energy. If the spot is resting at ground potential then the secondary emission ratio is unity and no change takes place. If the spot goes positive by a small amount it is in an area where the secondary emission ratio is less than unity so it charges back down to collector potential. If the spot goes slightly negative then the secondary emission becomes greater than unity and it charges back up to collector potential. Thus any spot initially charged to collector potential is held at that potential by the holding gun electrons.

Recent reports (Dodd, Klemperer, Youtz 1) indicate

that 16 tubes are being operated in parellel with their output signals being obtained simultaneously on separate lines. An access time of 25 u sec has been found to give good reliability by providing for rewriting and increased holding time

WILLIAMS TUBE: (Williams & Kilburn,17)

The Williams technique of storage was developed by Prof. F. C. Williams and Mr. T. Kilburn at the University of Manchester, England. The tube is different from others used as storage units in that an ordinary 7" cathode ray tube with an external target plate is used, rather than a tube designed for the specific purpose of storage.

Results of the work done by Williams and Kilburn were first presented in 1948. At that time there was considerable interest in the possibilities of using a storage tube as the memory unit in digital computers. Since few tubes designed specifically for this purpose had been constructed, several different groups started experimenting with the Williams technique. Some success has been achieved although the complete capabilities of the tube, as described by Prof. Williams, have not been realized. At the present, several organizations are actively engaged in work with the Williams tube, with the hope of developing a reliable, operable system.

1. Operation.

Input signals are either short or long duration pulses applied to the control grid of the gun during scanning. This results in either a single spot of charge being deposited on the sereen, or an elongated spot, or dash, of charge being deposited. Output pulses are taken from the external metal target as either positive or negative pulses. The polarity of the output pulses is determined by the nature of the charge deposited by the writing beam; i.e. whether a dot or dash has been written.

[illegible]

2. Theory.

Since the Williams tube makes use of effects not heretofore discussed a short discussion on the theory of the tube operation will be given.

a. Potential distribution of a single spot: If an electron beam is switched on and directed toward a single spot on the CRT screen, a net loss of electrons results if the accelerating potential exceeds the first crossover of the screen material. Consequently this spot reaches a potential slightly higher than the potential of the collector, (See page 15 par 2) and secondaries are ejected into a retarding field. As a result, electrons with low emission velocities will be returned to the screen. Some will return directly to the spot under bombardment but others with high velocities, but not high enough to reach the collector, will acquire a component of velocity parallel to the screen surface and will land in the vicinity of the spot. Experiments indicate that for bombardments less than 400 microseconds the surface is unaffected at distances greater than a spot diameter from the target. This redistribution of secondary electrons produces a potential distribution as shown in Fig.a.

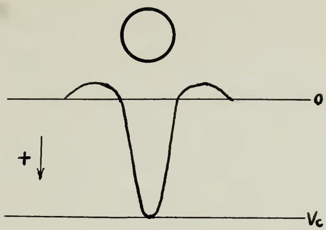


Figure a
Potential Distribution of
Single Spot

Positive direction is down. The depression in the distribution is termed a potential "well". This effect will be integrated with other effects to be described, to produce the output signals.

b. Effect of interrupting the beam to a single spot: With the beam directed at a single spot, assume equilibrium as described in Section 1 has been reached. The beam is now pulsed on and off at a frequency of 1KC/sec. by applying a series of square waves to the control grid. Between "on" periods substantially no change occurs in the charge pattern since the leakage time constant of the phosphor is large compared to the pulsing cycle. Since the potential of the spot is

slightly positive with respect to the collector, at the instant of switching on the beam a cloud of electrons consisting of secondaries and some primaries is introduced near the face of the target. This is equivalent to bringing a negative charge near the target plate, and a transient current flows to the plate to supply the required induced positive charge. When the beam is switched off, the opposite effect occurs and a positive pulse is produced. This effect is shown in Fig.b.

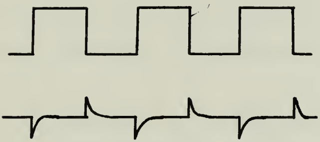


Figure b

c. Spot Separation. A square wave, having half the frequency of the grid modulating wave form and phased relative to it as shown in Fig.c is applied to the deflecting plates. Two spots, as shown at positions 1 and 2 in Fig. c will be obtained.

If the spot is initially at 1 a potential well will result. If the beam is switched off, and then switched on at position 2 the potential well shown

dotted will result.

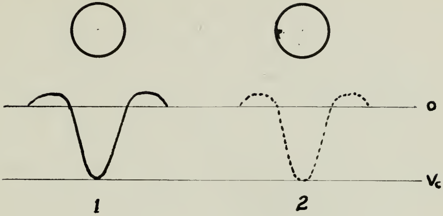


Figure c

Assuming the spot separation is greater than 1.3 spot diameters repeated switching of the beam results in the output shown in Fig.b.

If the spot separation is less than 1.3, as shown in Fig.d, some of the secondaries emitted during the evacuation of well 2 will be attracted to well 1 and partially refill it as the figure shows. The extent to which this refilling occurs is dependent upon spot separation and time of bombardment.

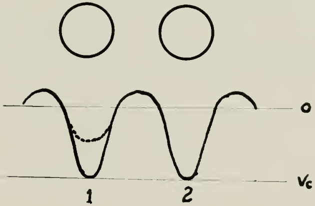


Figure d

The partial refilling of well 1 results in a potential distribution corresponding to a secondary emission ratio greater than unity, since for unity ratio the well potential must be V_c. Thus, if the beam is moved back to position 1 and switched on, well 1 is re-evacuated and well 2 is partially refilled. Therefore, with the beam directed to an area of spots separated by less than 1.3d, at the instant of switching on the beam, an output pulse is produced that is the sum of three separate pulses; that due to evacuating a partially filled well to field depth, that due to partial refilling of an adjacent well, and that due to the introduction of an electron cloud.

The evacuation of a partially filled well to full depth establishes a positive charge on the target spot under bombardment. This requires an equal negative charge on the target plate, resulting in a positive output pulse.

The partial refilling of an evacuated well means the addition of negative charge at that spot. This requires an equal positive charge on the target plate, producing a negative output pulse.

As previously explained, the electron cloud produces a negative output pulse.

Each of these pulses, and their sum are shown in Fig.e.

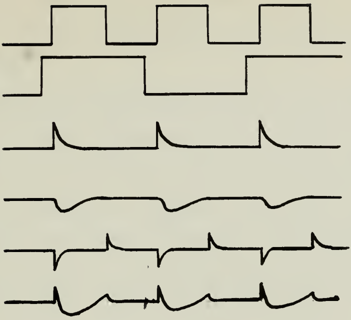


Figure e

From the preceeding discussion it is seen that either of two states of charge can be left on the target. They are:

1. By bombarding a single spot, ceasing bombardment and not bombarding any other spot in the vicinity, a spot at equilibrium potential is produced. When interrogated this spot produces a negative output pulse as discussed on page 54 par. b
2. By bombarding a single spot, then bombarding another spot in the same vicinity ($< 1.3d$) a partially filled well results. This gives a potential slightly negative with respect to the equilibrium potential. When interrogated this spot produces positive output. Actually the

beam is merely moved along the target to produce this potential distribution.

3. Writing.

Writing is accomplished by scanning the target at a uniform speed and applying positive pulses to the electron gun control grid to pulse the gun on and off. Positive pulses are initiated at regular intervals, approximately ten microseconds, and have one of two time durations, either two micro-seconds or 5 microseconds depending on the information to be stored on a given element.

The two-microsecond pulse produces a "dot" on the target face. This dot will have the potential distribution shown in Fig. a, and is used to represent the digit zero.

The five-microsend pulse produces a dash on the target face. In this case the beam will shift that portion initially bombarded to the equilibrium potential V_c. However, as the beam moves to other portions of the dash, some of the redistributed secondary electrons from these portions will land on the first part of the dash, shifting this portion to a potential somewhat negative with respect to V_c. See Fig.d. The dash represents the digit one. Thus each element will have stored on it a dot whose potential is V_c or a dash whose potential at the initial portion is less than V_c.

4. Reading.

Reading is accomplished by directing the beam at a dot or the beginning of a dash and switching it on. As explained

in the section on theory of operation if the beam is directed at a dot a negative output pulse results; if it is directed at a dash a positive output pulse is obtained.

Fig. b shows the output pulse obtained when the beam is directed to a dot and pulsed on and off. A negative pulse is produced when the beam goes on and a positive pulse results when the beam is turned off. Since it is not desirable to have the positive pulse from the dot appear in the output, the output is sampled only for a short period when the beam is pulsed on. In this way only the negative portion of the dot and the positive portion of the dash appears in the output from the target plate.

Holding: Using the method of reading as described, reading can be accomplished only once since each dot and the initial portion of each dash will be left at V_c. This is undesirable since it is often necessary to read a single address several times. To overcome this difficulty a regeneration process is incorporated in the reading. A feedback arrangement samples the output pulse before the reading pulse is ended. This controls the reading pulse so that a negative output, indicating a dot, shuts the beam off at the end of two microseconds. If the output is positive, indicating a dash, the reading pulse is lengthened to five microseconds, thus rewriting the dash. In this way the dots and dashes are retained by the target surface after reading.

5. Erasing:

If it is desired to erase the stored information then

each digit is read without the feedback circuit in operation. This leaves each dot at V_c and the beginning of each dash a V_c. Thus dots or dashes can be rewritten as described in the paragraph on Reading.

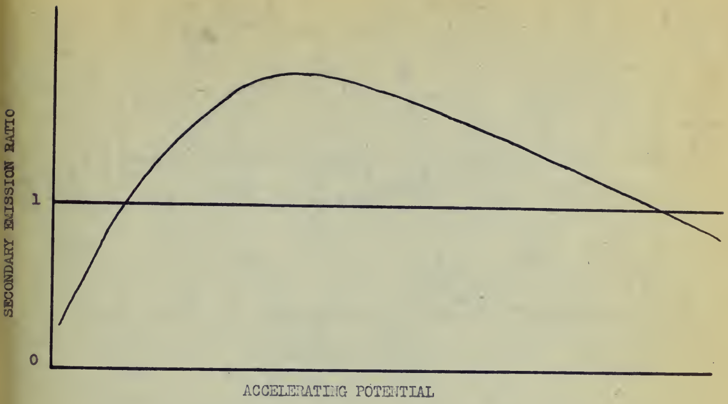


FIGURE 1

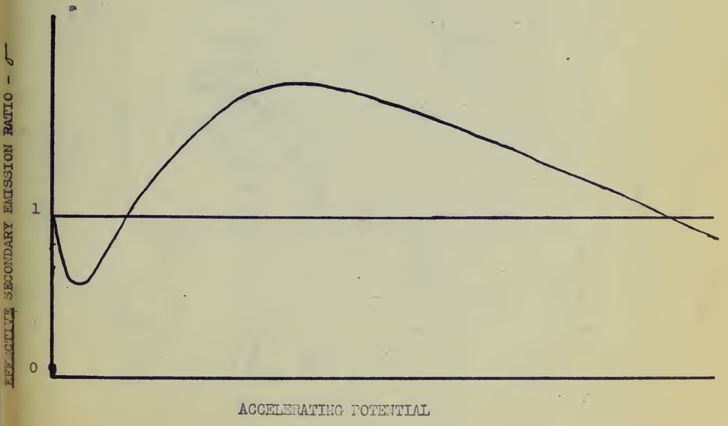


FIGURE 2

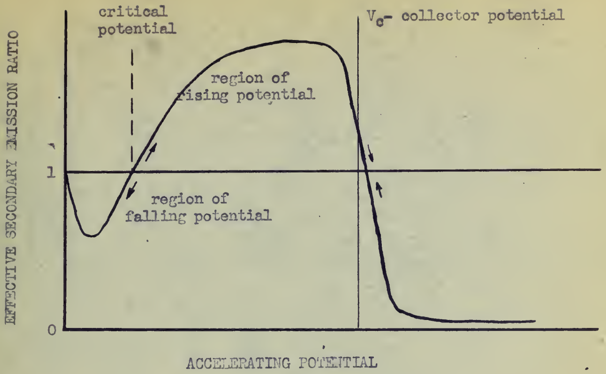


FIGURE 3

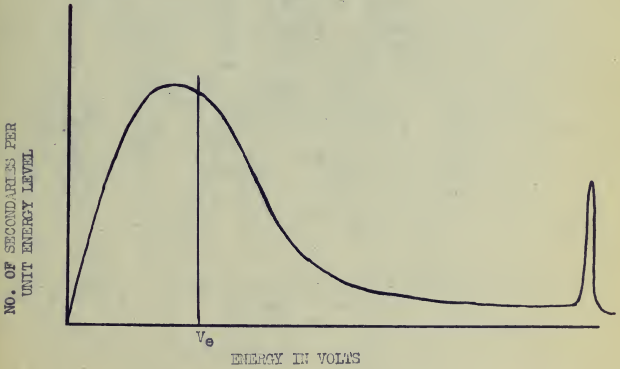


FIGURE 4

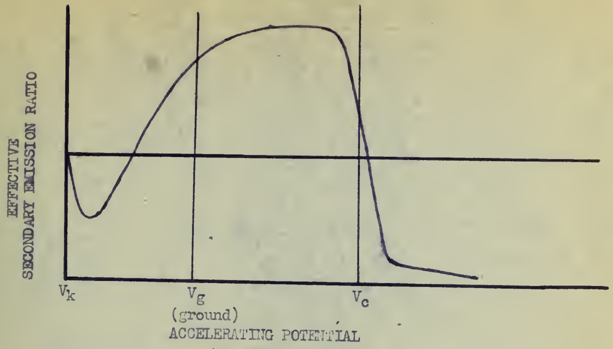


FIGURE 5

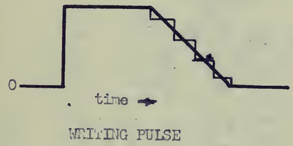


FIGURE 6

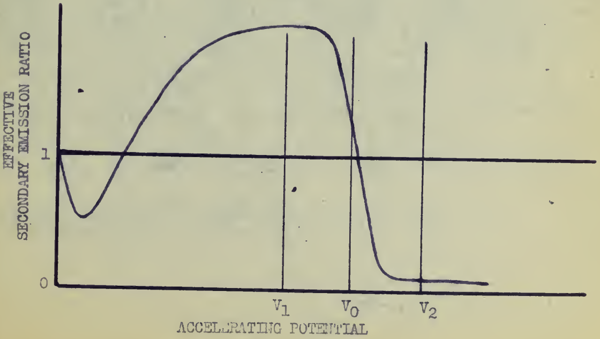
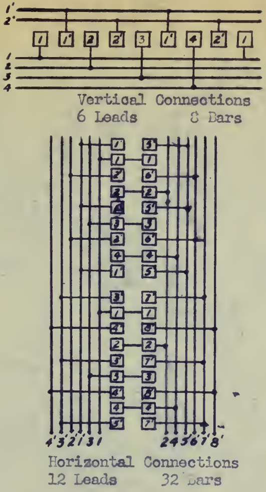


FIGURE 7

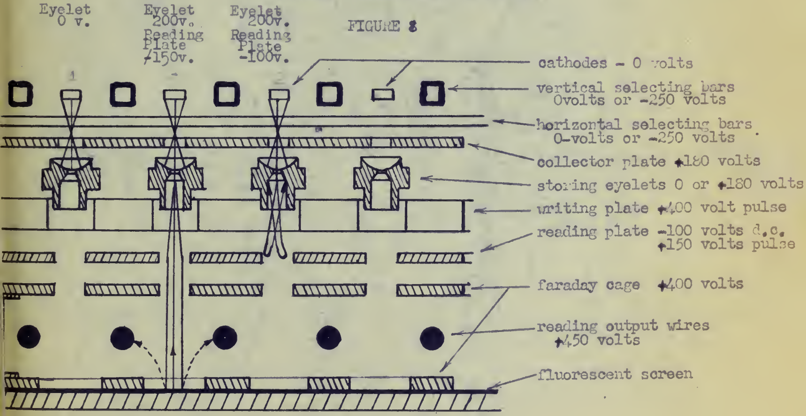


Total Leads $6 + 12 = 18$

Total Elements $8 \times 32 = 256$

INTERNAL CONNECTIONS FOR SB-256

FIGURE 8



OPERATING PRINCIPLES OF SB-256

FIGURE 9

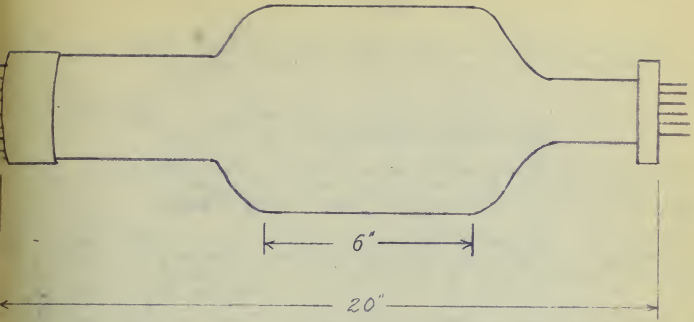
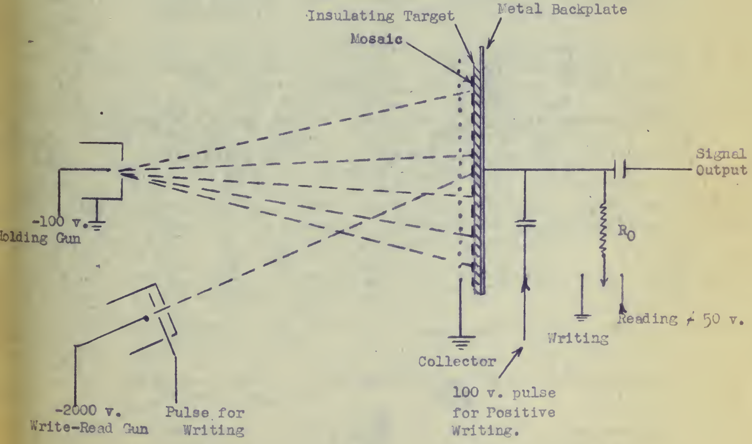


FIGURE 10



IGURE 11

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JAN	1
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